Economics and Science of Hog Manure Handling and Storage technologies

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Abstract

Hog production has been growing rapidly in Canada and this growth has created concerns over manure handling and the risk of soil and water contamination. There is limited information available to swine producers as to which technologies and manure management systems would best serve them both economically and environmentally. The objective of this study is to assess hog manure handling and storage systems and outline their environmental advantages and disadvantages. Five main technologies are reviewed which include (1) manure handling, (2) solid/liquid separation, (3) composting, (4) land application, and (5) manure storage. The average cost of hauling liquid manure within 2-3 mile distance is about $0.0125. If the total cost of hauling liquid manure is charged against its nutrients value, the producer cannot afford to haul much more than 2 to 3 miles; therefore, there is a restriction on the distance that manure can economically be moved and the availability of suitable land for manure application becomes a concern. Because of this restriction, manure treatment and the technologies for manure management such as solid/liquid separation or composting become attractive technologies to consider both economically and environmentally. Liquid/solid separation is a step in a complete manure treatment system and it has been utilized to reduce odour and manage phosphorus. There are different technologies available for solid/liquid separation which cost anywhere from $1.22 to $5.38 per pig marketed. Composting could also be utilized in swine manure management but because of high moisture contents, a high carbon source or bulking agent is required. Composting itself could costs anywhere from $4.85 to $13.49 per tonne of raw manure composted depending on type of composting technologies used. Manure storage is also part of integrated manure management system which comes in three main forms: earthen, concrete, and steel. Earthen manure storage systems are the most prominent manure storage systems in Western Canada. The capital cost for earthen manure range from $0.0039 to $0.0953 per gallon depending on availability of equipments and materials and additional costs may also required for adding a liner of clay. Other types of storage system generally cost higher but they might be more environmentally friendly. Operation and maintenance costs of manure storage is mainly limited with seasonal labor for agitation the waste, removal of sludge, and performing pump outs.

Introduction

Hog production has been growing rapidly in Canada and that has created opportunities and challenges to deal with manure management and handling systems. Due to the increase in swine production, the need for land suitable for the manure application, within an economic transport distance, has increased. Decisions made about management related technologies and the application of manure mainly depends on environmental and economic components. A proper manure management system not only values economic impacts of manure but also considers environmental sustainability of the system. These costs and values can then be compared to alternative manure handling systems and fertilizer applications. The key issue for whether to apply manure is therefore to consider both environmental and economic impacts simultaneously. The information available to producers as to which technologies and management systems would best serve them economically and environmentally is limited. Our objective is to review and provide information for swine producers on economic and environmental assessment of different manure managements and land applications of hog manure.

Methods: Economic Analysis

The economic performance of the different swine manure handling and storage technologies was determined using either published figures, manufacturer quotes or computed values using spreadsheet and standard budgeting techniques based on lifespan and typical work rate of machinery or equipment (SAFRR 2002). The basis for calculating the machinery cost was the cost of new equipment assuming 10 to 15% discounted manufacturer's suggested retail price. The total cost was divided into categories of fixed costs and repair and maintenance costs. Three main costs were considered to compute total fixed cost associated with a use of equipment: 1) depreciation, 2) interest on investment, and 3) insurance and housing, if applicable. The annual equipment cost and the total annual system cost were calculated based on typical work rate of the equipment, its lifespan, and the annual hours of use of equipment for the purpose of manure management. The labor costs used for machinery were calculated according to the machinery work rate and assumed on average 12 to 15 dollars per hour depending on the job. Unless otherwise stated, all dollar figures are in Canadian dollars. The exchange rate in the conversion from US dollars to Canadian dollars at the time of calculations was 0.76.

Results and Discussion

1. Liquid Manure

Manure has been recognized as an organic fertilizer containing essential nutrients required for crop production. Based on research from Iowa State University (Brenneman, 1995), a farrow-to-finish swine operation marketing 1,500 head produces 450,000 gallons of manure per year, or 300 gallons for each hog marketed. The value of these nutrients is approximately \$15.80 per 1,000 gallons, for a total fertilizer value of \$7,110. If the total cost of hauling the manure is charged against the fertilizer value of \$7,110, the producer cannot afford to haul much further than 2 or 3 miles as the cost of hauling liquid hog manure is about \$15.80 per 1,000 gallons for 2 to 3 mile distances. Due to the cost associated with transporting and applying liquid manure, there is a restriction on the distance that manure can economically be moved (Nagy et al., 2000). Manure can increase the soil's productivity and crop yields by providing large inputs of nutrients and contributes to improved soil tilth, fertility and structure due to the addition of organic materials. These values will not be typically included in a farmers' management strategies because the benefits of maintaining and/or enhancing soil tilth from a year's application of manure are small, occur in future years and are hard to quantify.

Nitrogen Availability

Figures across the prairies vary on the availability of nutrients, especially nitrogen. Until recently, it was a generally accepted rule of thumb that 50% of total N in manure was available in the first year of application (SAFRR, 2000). However, research with hog manure has shown that the 50% estimate falls short of actual availability. In Saskatchewan field trials over 2 years with hog manure, Schoenau (1998) showed that for liquid hog manure, 40% (fall applied) and 75% of total N (spring applied) is available in the first year of application. An additional 20% of the total N is also mineralized during the growing season. From these results, during the first year after application, 60 to 95% of total N is available to the plant. Similar N availability has been shown in a recent Manitoba Agriculture fact sheet "Calculation of Manure Application Rates". Accounting for losses, available N from liquid injected hog manure is estimated at 80% in the year of application (Manitoba Agriculture, 1998).

Phosphorus Availability

Phosphorus (P) is present in both inorganic and organic forms. For plant availability, phosphorus must be in solution as a phosphate (P_2O_5). Schoenau (1998) documents available P, in equivalent P_2O_5, in liquid hog manure as 22% and 47% for fall-applied and spring-applied manure, respectively. An assumption of 40% availability is often suitable in situations were lab testing of the soil is unavailable.

2. Solid Manure

Solid manure handling systems have not gained popularity in Canada (Tessier and Marquis, 1999). Accordingly, less than five percent of swine operations have adopted the solid manure systems and most of those are small operations. If a solid manure system is used in an intensive swine operation, the source and cost of straw, as well as the disposal of the straw manure mixture, should be considered. It is estimated that the straw requirement for breeding and gestation facility to be typically 750 to 800 kg (2.5 bales) per sow place per year. The cost is estimated to be \$25 to \$30 per sow place per year depending upon the price of straw. For a finisher facility, the straw requirement is estimated to be 90 kg, or \$3.20, per pig marketed. Typically, a producer handling solid manure land-applies the manure more frequently than a producer who uses a liquid system, which means producers using solid systems must have application fields that are available year round.

3. Liquid-Solid Separation

Liquid-solid separation is usually used as a step in a complete manure treatment system. However, liquid-solid separation has been utilized for two other purposes. One of these is to reduce odour (Lorimor et al. 1998). It is thought that the decomposition of the solid components in swine manure contributes in a large part to odour production. In fact, fine particulates of swine manure are more readily decomposed than larger fractions and typically contribute more to odour generation (Jamieson et al. 2001). This emphasizes the requirement to remove as much solid material as possible during the separation procedure. The other goal of liquid-solid separation is to manage phosphorus (Ford and Fleming 2002). In some regions, phosphorous loading in the land receiving manure is an issue, and the nitrogen/phosphorous balance in the raw manure may not match the crop requirement. Because most of the phosphorus in swine manure is found in the solids, separating the liquids from the solids allows more precise management of the nitrogen/phosphorus ratio of the manure applied to the land.

Separators can be classified into three main classes: screen, centrifuges, and presses (Ford and Fleming 2002). Screen separators have a screen over which the manure is passed and particles smaller than the screen size pass through with the liquid. Centrifuges use centrifugal force to separate particles of different density. Presses exert mechanical pressure on the raw manure to provide additional separation. Each type of separation performs differently in specific situations.
Table 1 shows examples of the cost for different solid-liquid separation technologies for a 200 sow farrow to finish operation. The cost includes both fixed and annual operation and maintenance of solid-liquid separation.

Table 1. Cost of solid-liquid separation

Fixed and O&M	Screw Press	Belt Press	Centrifuge	Rotating screen	Vibrating Screen	Incline screen	Settling basin
Cost per pig marketed	$1.95	$3.48	$5.38	$1.74	$1.56	$1.22	$1.92

Assumptions: $1.00 CDN equals $1.02 AUS; 200 sow operation producing 3,500 marketed annually (2.26 cycles per year, 10 piglets per cycle); Labour for monitoring and maintenance at $ 12/hr; cost per kWh is $0.066; interest rate of 8%; 10% salvage value on all but settling basin; settling basin has 5% salvage; cost of diesel fuel at $0.38 per litre; oil and lube estimated at 15% of fuel cost
Source: Watts et al,, 2002.

Two or more solid-liquid separation technologies may have to be combined in order to attain the desired moisture content and solids removal. For example, presses are often used as a secondary solid-liquid separation technology since they perform better with higher solids content effluent.

The addition of chemicals to effluent can enhance the separation process. The chemicals act to coagulate and flocculate the particles in the effluent. The process of coagulation causes suspended solids to form into particles which will settle while flocculation converts particles into large flocs which will also settle.

Chemicals used for coagulation flocculation can increase nutrient removal from the effluent. For example, the addition of a polymer combined with the use of a centrifuge separator can increase the removal of nitrogen from 13% to 31% and phosphorus from 66% to 75%, as compared to centrifugation without coagulation and flocculation (Van Kleeck 1994).

Costs associated with combining this technology with solid-liquid separation techniques include the cost of chemicals and labour or equipment for adding the chemicals. Polyacrylamide costs $6/kg and can be incorporated at a rate of 5 mg per litre of waste (Watts et al. 2002). For a 5,000 head space finishing operation producing 0.15 ft^3 of waste per animal per day, the annual chemical cost of adding polyacrylamide is $23.26 or less than $0.01 per marketed hog.

The use of solid-liquid separation technology can decrease costs associated with manure management. Removal of solids makes the liquid easier to pump, thus reducing the complexity of pumping systems. The frequency of sludge removal can also be reduced, reducing associated labour and machinery costs and potentially reducing wear on storage liners and covers.

4. Composting of Swine Manure

Composting is an aerobic process requiring oxygen, moisture, carbon and nitrogen in the proper ratios for the correct bacteria to thrive. The heat generated from microbial activity causes the initial temperature of the compost to rise to 50-70°C. The carbon to nitrogen ratio (C:N) in the raw material is critical to promote efficient microbial activity. The optimum ratio is 30:1 and anything less than 20:1 C:N can result in odour production. Swine slurry has a C:N ratio of 16:1 and moisture levels exceeding 75%, therefore a high carbon source or bulking agent is required and there is a need for solid-liquid separation before manure can be composted. Swine operations, such as deep litter housing, do not require a bulking agent as the litter provides the carbon source.

There are three main composting methods: Outdoor Pile, Windrow and In-vessel. Outdoor pile and windrow composting systems consist of mixing and piling organic wastes on an outdoor platform. They require 12-18 month range of processing time, and may require a considerable land base due to the retention time. An impervious base, such as a concrete pad, and drainage are required to control leachate. It is generally estimated 1 m^3 of raw material requires 0.8 m^2 of ground area for a windrow system. The common arrangement for these batch processes is to have multiple piles or windrows in various stages of processing. Aeration is passive in these systems, either by burying an aeration pipe in the pile or the base or a combination of both. Forced aeration can be used as well.

In-vessel compost systems employ a concrete channel or trough to hold the compost inside a building. The in-vessel systems have tighter quality control than windrowing or piling outdoors resulting in more consistent compost. Forced aeration is typical and turning is more regimented. The relative aggressiveness of the processing lowers land requirements to 20% of an outdoor windrow system. Due to its comparatively short processing time of 4-8 weeks, it is best suited for continuous treatment. Raw materials can be added at one end of the channel while finished product is removed from the other end of the channel. Portable batch models are available which partially compost small batches in 3-6 days.

The cost components of the different systems are provided in Table 2. The difference in housing and pad costs between the two windrow-composting systems is due to the increased space needed between windrows in the pull-type system. The annual cost for outdoor pile composting is about $7.50 per tonne of raw manure composted. For self-propelled windrow composting the annual cost is $7.47 per tonne of manure, $8.73 with a base or $13.49 per tonne with both base and roof. With pull-type windrow composting the annual cost associated with composting is $4.85, $6.66 and $13.45 per tonne of manure for no base, base and roof and base concepts, respectively. The use of a roof over windrows is necessary for regions of the country with high levels of precipitation, such as British Columbia. The cost per tonne of manure composted using in-vessel composting is about $13.01 for 4 ft. channels and $10.80 for 8 ft. channels, the difference being found in the size requirements for the building and the time needed.

Table 2. Annual cost to compost 6,300 tonnes of manure per year

Composting System	Operating Cost*	Equipment Cost*	Pad & Housing Cost*	Total*
Pull-type turner	$5,815	$24,750	-	$30,565
Pull-type turner with base	$5,815	$24,750	$11,392	$41,957
Pull-type turner with roof and base	$5,815	$24,750	$54,227	$84,792
Self propelled turner	$5,815	$41,250	-	$47,065
Self propelled turner with base	$5,815	$41,250	$7,975	$55,039
Self propelled turner with roof and base	$5,815	$41,250	$37,959	$85,024
In-vessel (4 ft. channels)	$8,639	$27,390	$45,984	$82,013
In-vessel (8 ft. channels)	$3,745	$33,900	$30,378	$68,113

*Assumptions: 8% interest, depreciation rates based upon 5 yr life span on turning equipment and aeration system,15 yr life span on buildings and in-vessel composter and 25 yr on asphalt base, maintenance and repair based on the original value of the item (5% on equipment, 1% on buildings, 0.5% on asphalt, 10% on aeration system), and fuel and electricity (diesel $0.38/litre and electricity $0.065 per kWh), labour at $15/hour.
Source: Modified from Paul J., 1999.

The annual cost of bulking agent will depend upon the quantity of manure to be composted and the needs of the compost in terms of C:N ratio and moisture control. This cost is expected to be $81,900 for 6,300 tonnes of manure composted ($13 per tonne) annually. To reduce the costs associated with adding bulking agent to control the moisture level, solid-liquid separation can be used, but such processes require specialized equipment and thus increase costs.

5. Land Application of Liquid Manure versus Solid Manure or Compost

There are four main categories of swine manure land application techniques including broadcast (no incorporation), broadcast and incorporated, high disturbance injection and low disturbance injection. Broadcast (no incorporation) includes broadcast spread, dribble bar, traveling gun and pivot irrigation. Broadcast and incorporated includes the previous application methods plus tillage operations that incorporate the manure to prevent runoff, reduce odour and reduce ammonia-N losses. High disturbance injection refers to the use of a tool bar equipped with a manure distribution manifold, shanks and sweeps for opening and tilling the soil. Boots are attached to the back of the shanks to direct the manure into the opening created behind the sweeps. The sweep openers operate from 2 to 6 inches (5 to 15 cm) deep in the soil depending on the manure application rates and soil conditions. Low disturbance injection typically refers to the use of toolbar mounted coulters to open the soil with a minimum of soil disturbance. Coulters penetrate the soil to a depth of 3 to 6 inches (7.5 to 15 cm) and are suitable for injecting the manure into a wide range of soil and crop conditions including zero till farmland, pastures and forages in addition to conventional till cropland.

Broadcast liquid swine manure is subject to nitrogen losses as high as 40% and the manure is subject to runoff losses. The retention factor is 0.85 for broadcast with incorporation within 24 hours and 0.65 for broadcast with no incorporation. Injection of liquid manure reduces volatilization losses (retention factor is about 1) of nutrients such as nitrogen and increases the crop's ability to access the nutrients in the hog manure (Mooleki et al. 2001). Injection has also been shown to reduce odours associated with land application and allows the land to use the applied nutrients more efficiently.

Reports state that land application of liquid manure costs one cent per gallon and using injection may add about $0.003 per gallon as compared to broadcasting. Table 3 shows the cost of liquid manure injection.

Table 3. Manure Injection Costs

Radius (miles)	Price ($ per gallon)
1-2	$0.0097
2-2.5	$0.0115
2.5-3	$0.0135

Source: Industry Standard; Halter 2003

Application of liquid manure has to compete with solid manure and compost application where all three options are available. Applying solid hog manure or compost to crop fields incurs additional costs that should be compared with liquid application of hog manure. These additional costs include the purchase and operation of a separation unit, the addition of bulking agent unless the facilities have a solid manure system with straw or sawdust, and the composting cost itself. As stated earlier, land application of liquid manure costs one cent per gallon and using injection may add about $0.003 per gallon as compared to broadcasting. Assuming 0.0054 kg of nitrogen per kg of solid manure, $3.53 per tonne transportation cost within 13 km, $16/ha for spreading, and assuming fertilizer recommendation of 112 kg N per ha, it is required to apply 20.74 tonnes of manure per ha. This means solid manure application costs $89.20 per ha or $4.30 per tonne of manure. For compost, the costs are $119.40 per ha or $10.61 per tonne, based on assumptions of 0.00996 kg of nitrogen per kg of compost, $1.69 per tonne transportation cost within a 13 km distance, $16/ha for spreading, $7.50 per tonne for composting, and a fertilizer recommendation of 112 kg N per ha, resulting in 11.25 tonnes of compost required per ha. The additional costs of solid/liquid separation and adding bulking agent are not included in this calculation. The further the hauling distance from a hog operation to field (spreading) site, the greater the relative associated costs for manure versus compost and therefore, more beneficial to apply compost than manure.

6. Manure Storage and Costs

Manure storage comes in three main forms: earthen, concrete and steel. Earthen manure storage systems (EMS) are the most prominent manure storage systems in Western Canada. Two forms of EMS are recognized: earthen basins and lagoons. Earthen basins or holding ponds are typically smaller than lagoons and have limited capacity for manure treatment, either aerobic or anaerobic. Lagoons are significantly larger and handle more diluted manure.

The initial costs of manure storage will depend greatly upon the size and type of operation, which will dictate the volume required for waste storage. Tables 4 and 5 show the volume of manure produced and the required storage space per pig and examples of storage requirements for a farrow to finish operation, respectively.

Table 4. Daily manure production and storage volumes

Class	Age	Manure Production		Required Storage for Liquid manure *	
		litres/pig	ft^3/pig	litres/pig	ft^3/pig
20-90 kg	8-22 wks	5.1	0.18	7.1	0.25
5-10 kg	3-6 wks	1.1	0.04	1.6	0.06
10-25 kg	6-9 wks	2.3	0.08	3.1	0.11
25-35 kg	9-12 wks	3.4	0.12	4.8	0.17
35-60 kg	12-16 wks	5.1	0.18	7.1	0.25
60-80 kg	16-20 wks	7.4	0.26	10.2	0.36
80-90 kg	20-22 wks	9.1	0.32	12.7	0.45
Dry Sow		11.3	0.40	15.9	0.56
Nursing Sow and Litter					
Wean @ 3 wks		15.6	0.55	21.8	0.77
Wean @ 6 wks		19.5	0.69	27.5	0.97

*Calculated from 'manure production' by a multiplying factor of 1.4 to account for spillage from waterers, floor washing and dilution water where required. These figures total to 60-75 L/(sow.day) for the entire farrow -to-finish herd. Depending on location, additional volume may be needed to allow for rain and snow collected in open storages.
Source: West and Turnbull, 1989.

Table 5. Liquid manure storage requirements (Farrow to finish)

Herd size (sows)	6-month storage m^3	6-month storage gallons	Land space (ft^2) **	12-month storage m^3	12-month storage gallons	Land space (ft^2) **
50	550	145,300	3,900	1,100	290,600	6,600
100	1,100	290,600	6,600	2,200	581,200	11,500
150	1,640	433,200	9,100	3,280	866,500	16,100
200	2,190	578,500	11,500	4,380	1,157,100	20,700
300	3,300	871,800	16,200	6,600	1,743,500	29,700
500	5,500	1,452,900	25,200	11,000	2,905,900	47,000

Based on 60 litres per day per sow waste production
** - calculated assuming storage depth of 10 ft, side slopes of 1:2
Modified from West and Turnbull, 1989.

Sizing the storage to hold less than 365 days of waste may reduce capital costs associated with these technologies. When analyzing this option, the reduction in capital costs should be weighed against any increased costs that may be incurred by requiring multiple field applications. A downside of downsizing the storage is that multiple applications could result in soil compaction, depending upon the type of application equipment used.

Another factor influencing the cost of storage will be storage type. The cost for deep-pit storage below the hog barn can cost from \$0.1407 to \$0.1795 per gallon (Zhang and Mukhtar 1995). Additional land is not required for this storage type and very little nutrient value is lost, but there are problems associated with odours and toxic gases within the barn. There are several options for storages located externally to the production barns.

The cost for earthen manure storages, either lagoon or earthen basins, ranges from $0.0039 to $0.0953 per gallon (Harmon 1996, LPES 2004, NPPC 1999(a,b,c), Tyson 1998, Lakshman 2000, Rausch and Sohngen 1999, SOTF 1995, Zhang and Mukhtar 1995). With earthen storages additional capital costs can be found by adding a liner of clay, plastic or concrete. Plastic lagoon liners can add $0.33 to $5.26 per square foot to the total cost (USEPA 2001(a)). The added cost of clay liners ranges from $0.045 to $0.065 per gallon (LPES 2004) of storage, depending upon the distance the clay has to be hauled.

Manure storages constructed of concrete can cost from $0.0545 to $0.2606 per gallon (Harmon 1996, LPES 2004, Fulhage et al 2002, Gronaurer and Schattner 2001). A square concrete storage costs more per gallon than a circular storage due to the added support structure needed (LPES 2004). Costs of concrete storages can also be reduced by having prefabricated components assembled on site as opposed to the concrete being poured on site (LPES 2004). Constructed steel tanks can cost from $0.1316 to $0.2643 per gallon (LPES 2004, Fulhage et al 2002, Zulovich et al 2001).

It should be noted that economies of scale suggest that the cost per gallon for larger operation will be less than those for smaller operations and the total cost on a per pig basis should also be less for a larger operation.

A permanent cover can reduce the cost of the storage by eliminating the need for the extra 20% of required volume for precipitation. The cost of the cover should be taken into account when a cover is being considered for the sole purpose of reducing storage size.

Operation and maintenance of manure storage is limited. Most of the labour will be seasonal for agitation the waste, removal of sludge, and performing pump outs. Sludge shouldn't be completely removed from earthen manure storages; some sludge should remain as it acts as an additional barrier for leakage and seepage and protects the liner from damage. Additional labour may be required to maintain the area around the storage. Steel and concrete slurry tanks have higher labour costs associated with them as compared to deep pit storage (Unterschultz et al 2003). The transfer of manure from the hog barn to the storage occurs frequently and thus requires more management and labour as compared to a deep-pit storage. Automation of the scrapers and pumps can reduce the labour required but adds to the capital cost of the system. Mechanical scrapers also require more maintenance and repair as compared to gravity draining gutters or slotted floors.

Maintaining the outside berm is crucial in an EMS. Trees should not be allowed to take root and animals should not be allowed to burrow in the banks. Care should be taken not to cause undo erosion or liner disturbance during agitation. Maintenance costs for storage liners are estimated at 5% (USEPA 2001(a)), due to potential damage that can be incurred during sludge removal.

If the storage cannot be filled by gravitational means, a pumping system may be required. Manure pumping systems cost from $33,000 to $46,000 (Zulovich et al 2001) and will have annual labour, repair and maintenance and electricity costs associated with them. Pump sizes of 1 to 5 hp are suggested (West and Turnbull 1989), and assuming that the pump is running 8 hours per day with a per kilowatt-hour rate of $0.066, the annual electricity cost will be from $150 to $750.

The loss of nutrient value in earthen manure storages as compared to slurry tanks and deep-pit storages (WRAP 2000, Unterschultz et al 2003) could also be seen as an increased cost as additional commercial fertilizer may be need to supplement the loss.

Conclusion

Limited economic/environmental information available to hog producers regarding swine manure management technologies have led to an assessment of five main technologies including (1) manure handling, (2) solid/liquid separation, (3) composting, (4) land application, and (5) manure storage. The average cost of hauling liquid manure within 2-3 mile distance is about $0.0125. If the total cost of hauling liquid manure is charged against its nutrients value, the producer cannot afford to haul much more than 2 to 3 miles. Other technologies may provide benefit to swine producers in terms of better managing their hog manure. Liquid/solid separation is a step in a complete manure treatment system and it has been utilized to reduce odour and manage phosphorus. There are different technologies available for solid/liquid separation which cost anywhere from $1.22 to $5.38 per pig marketed. Composting could also be utilized in swine manure management but because high moisture contents, a high carbon source or bulking agent is required. Composting itself could costs anywhere from $4.85 to $13.49 per tonne of raw manure composted depending on type of composting technologies used. Earthen manure storage systems are the most prominent manure storage systems in Western Canada and the have comparatively lower costs. Circular steel storage is the most ground water friendly storage system but its limited capacity and comparative higher costs are a drawback. Covered lagoons with an engineered liner are the best system for large volume manure handling provided the producer can afford the space requirement of the lagoon and has the land base to apply the manure on. Concrete storage is feasible in regions where EMS systems are not permitted.

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